TRAFFIC FLOW MANAGEMENT (TFM) WEATHER REROUTING

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1. INTRODUCTION

During recent years, increased air traffic has intensified the impact of severe weather on the National Airspace System (NAS) (e.g., delays, cancellations, increased miles flown, and greater schedule uncertainty). In response, the Federal Aviation Administration (FAA), MITRE/CAASD, and the aviation industry are working to expand the use of technology to help alleviate air traffic delays caused by severe weather. Although the events of September 11, 2001 have resulted in a lowering of air traffic demand, we anticipate a return to high levels of traffic congestion.

Traffic Flow Management (TFM) is a domain in which technology may be especially beneficial. TFM redistributes traffic flow demand to conform to limited and varying NAS capacity. During peak hours, there can be from 4,000 to 6,000 aircraft operating in the NAS. Therefore, a line of thunderstorms extending for hundreds of miles across heavily utilized traffic corridors can result in significant nationwide disruptions in traffic flow. Accurate convective weather forecasts and automated decision support capabilities that can utilize these forecasts may help to lessen traffic delays. Recent convective weather forecasting advances, such as the National Convective Weather Forecast (NCWF), Collaborative Convective Forecast Product (CCFP), and Corridor Integrated Weather System (CIWS) may soon make it possible to leverage TFM decision support tools to more effectively address weather-related traffic flow restrictions.

The National Center for Atmospheric Research (NCAR) is developing an automated, national, deterministic forecast called the NCWF (Mueller, 1999). Currently, the NCWF has 1-hour predictions, 5-minute updates, and is limited to the extrapolation of existing convective weather. However, NCAR is working to add storm initiation, growth and decay (Mueller, 2000). These enhancements will increase the accuracy and length (i.e., out to 2 hours) of NCWF forecasts.

The CCFP (Mahoney, 2000) is a collaborative, national, probabilistic forecast, which extends out 6 hours. During the convective weather season, meteorologists from airlines and aviation weather organizations generate the CCFP every 2 hours. The CCFP is the convective weather forecast currently employed operationally by TFM and the airlines for collaborative strategic planning.

MIT Lincoln Laboratory (LL) is developing an automated, regional, deterministic forecast called CIWS (Evans, 2001) that capitalizes on the high density of FAA and National Weather Service (NWS) weather sensors in congested NAS corridors. CIWS will initially provide a 1-hour convective weather forecast, which will extend to 2 hours using new forecast techniques and additional weather data.

MITRE/CAASD is utilizing these weather forecasting advancements in its development of a concept demonstration platform called Collaborative Routing Coordination Tools (CRCT). CRCT (Wanke, 2000) is a set of decision support concepts and capabilities, currently under research and development that we envision to become components of the short and midterm traffic management tool set. "Baseline" CRCT functionalities are currently in operational evaluation at three sites: the Air Traffic Control System Command Center (ATCSCC) in Herndon, VA and the Air Route Traffic Control Centers (ARTCCs) in Kansas City and Indianapolis. Baseline capabilities include the following:

- Rerouting functionality that provides for manual entry of Flow Constrained Areas (FCAs);
- Automatic identification of aircraft predicted to penetrate FCAs;
- Manual rerouting of aircraft; and
- Assessment of the impact of proposed reroutes on sector traffic volume.

As individual CRCT capabilities mature, they are being tech transferred and integrated into the Enhanced Traffic Management System (ETMS) (Volpe Report, 2001) as operational capabilities.

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A new area of TFM research being developed by MITRE/CAASD is Automation-assisted Weather Problem Resolution (AWPR). AWPR builds upon the baseline CRCT platform by providing increased automation and initial integration of multiple strategies for addressing traffic congestion (i.e., rerouting, ground delays, and volume management). The objectives of AWPR are to reduce aircraft delays and cancellations, maximize aircraft throughput around areas of severe weather (or other constrained airspace), maintain safe levels of controller workload, and promote more effective user collaboration. This paper will discuss the following aspects of AWPR:

- Scope
- Research goals
- Operational concept
- Evaluation prototype
- Evaluation results
- Next steps.

2. SCOPE

The AWPR operational concept is a decision support capability providing strategic response to flow constraining convective weather. The concept assumes the availability of accurate 2-hour weather and traffic predictions. TFM weather rerouting and other integrated strategies included in this concept will occur within this 2-hour time frame, because of the difficulties involved in accurately predicting both weather and traffic beyond 2 hours. However, MITRE/CAASD intends to explore complementary concepts that will employ demand-reducing strategies in the 2-6 hour time frame. In addition, we are developing concepts for the complex interactions and collaboration among FAA and Industry users. We will address these additional concepts in future publications.

3. RESEARCH GOALS

AWPR research will address the following questions:

- How can AWPR leverage automation-assisted traffic rerouting capabilities and improved weather forecasts to effectively utilize limited airspace capacity in response to severe convective weather events?
- What are the weather requirements for such decision support automation? Will current weather forecasts suffice or will new or improved products be required?
- How will AWPR integrate these FAA weather rerouting capabilities with other TFM capabilities (e.g., volume management, ground delays, and Miles-In-Trail [MIT])?
- How will AWPR assess the operational benefits of this integrated tool set?
- How will AWPR address operational collaboration between the FAA and airlines?
- What will be the FAA and airline roles in future TFM weather rerouting?

4. OPERATIONAL CONCEPT

Although weather products have yet to combine both the forecast duration and accuracy needed for AWPR, the results of current weather research (Mueller, 2000, and Evans, 2001) look promising in a 2-hour time horizon. This weather forecast research, which is proceeding in parallel with AWPR concept development, involves algorithms and data that will enable forecasts to include storm initiation, growth and decay. It is anticipated that an acceptable 2-hour convective weather forecast will be available before capabilities based on this AWPR concept can be fully developed and incorporated into an operational TFM system (i.e., ETMS).

Another reason for the 2-hour limitation for weather reroutes is the scarcity of early flight plan filings (e.g., 2 hours before departure) or other early intent information. Early intent information will allow for improved traffic predictions and better reroute planning. Although few airlines file flight plans 2 hours prior to departure, this may become more common in coming years.

The AWPR concept assumes that some flights will desire a strategic reroute around severe weather, while others will tactically thread their way through the weather. This concept does not separate aircraft from weather. Rather, it manages traffic demand in sectors adjacent to weather or other classes of FCAs, in order to increase throughput and decrease delay, without exceeding available capacity. In other words, the idea is to effectively and safely utilize capacity in areas near severe weather and let the severity of the weather regulate the flow of traffic within the FCA.

Whereas current concepts involve manually drawn FCAs, the AWPR concept utilizes a computer-generated weather forecast (e.g., NCWF) to automatically define convective weather FCAs. Therefore, the concept provides information on rapidly changing weather situations, which allows for better reroute planning.

To limit rerouting to those aircraft that will penetrate severe weather, the concept identifies four-dimensional intersections between weather FCAs and aircraft trajectories. This selective rerouting set is an improvement over today's operational tools (i.e., MIT, ground delays, ground stops). These existing tools have a tendency to also impact aircraft that will not penetrate the weather and therefore are not directly contributing to the congestion problem. However, AWPR users may modify the list of aircraft selected for rerouting. For example, users may add aircraft arriving at or departing from airports near the weather or remove aircraft requesting to fly through the weather (e.g. pathfinders).

To effectively manage the flow of traffic through sectors that are in close proximity to areas of severe convective weather, the AWPR concept seeks to simplify the rerouted traffic patterns by defining reroute corridors. Therefore, although the rerouted traffic will add increased traffic volume to these sectors, it will not overly add to their traffic complexity. Further, in order to maintain adequate safety levels, the concept will not allow reroutes that exceed sector-loading thresholds. By limiting both traffic complexity and volume, the concept maintains acceptable levels of controller workload.

The integration of volume management and weather rerouting concepts is a first step towards an integrated set of TFM congestion management capabilities. The AWPR concept also includes a ground delay strategy for individual aircraft. Inactive flights that could be safely accommodated on reroute corridors, if their departures are delayed, may be assigned individual ground delays.

By utilizing several strategies working in concert, the AWPR concept may provide a better outcome than a concept that uses a single strategy or independently uses strategies that may act in conflict with each other. Integrated assessment of the TFM solution is also necessary to assure that multiple strategies are indeed combining well to provide favorable results.

The concept automatically assigns aircraft selected for rerouting to reroute corridors based on pre-defined decision logic and equitable allocation schemes. The decision logic employed includes addressing active flights before inactive ones and flights that have fewer reroute options before those that have more. To date, we have incorporated one equitable allocation scheme into AWPR (i.e., blind rationing – a scheme that does not consider air carrier information in the allocation of flights to reroute corridors). However, we intend to add several other allocation schemes for evaluation. We will evaluate these schemes in coordination with the Collaborative Decision Making (CDM) working group (http://www.metsci.com/cdm/index.html). The CDM is a joint government/industry initiative whose goal is to improve traffic management through improved decision support automation and increased information exchange within the aviation community. CDM participants include the FAA, air carrier industry, private industry, and academia.

Additionally, this concept allows for automatic assessment of planned reroutes. Assessment metrics include sector loading, extra air miles flown, total aircraft delay, and ground delay. If operational users find the assessment results unacceptable, they can modify and reassess the reroute plan. The AWPR concept relies heavily on automation to quickly create, modify, and assess plans, so that time can be set aside for human collaboration and decision making.

An essential element to weather reroute planning or other congestion management is ATCSCC, ARTCC, and Airline Operational Center (AOC) collaboration. We will be expanding the AWPR concept to include additional decision support concepts and capabilities to assist with this collaboration process. In April 2001, MITRE hosted an FAA/Industry workshop to discuss collaborative rerouting concepts for decision support capabilities (http://www.mitrecaasd.org/collab_wx_rerouting_workshop/index.html). We are using the information obtained from FAA and industry workshop participants to develop a concept of operations to extend AWPR capabilities to include a collaborative operational environment.

Next, AWPR electronically communicates reroutes and ground delays to controllers and airline dispatchers for implementation. The process for electronic transmission of reroutes and delays is currently under development at MITRE/CAASD. Because hundreds of reroutes and delays may be involved in a reroute plan, it is important that the communication process be computer-assisted.

The process described above must take place within about twenty minutes. This is necessary because of the limited duration of accurate convective weather forecasts and the dynamic nature of this type of weather. Also, for the same reasons, users will need to update TFM reroute plans often. As convective weather forecasts become more accurate at longer time intervals and as airlines file flight plans earlier, users may need to update reroute plans less frequently.

When users update reroute plans, they will leave intact those elements of previous reroute plans (e.g., reroutes and reroute corridors) that do not require alterations. The parts of the plan that may change include: addition of flight plans that were filed since the last TFM reroute plan, removal of existing reroute corridors that have become impacted by weather, and creation of new reroute corridors that take advantage of or react to new weather forecasts.

5. EVALUATION PROTOTYPE

This section illustrates the current implementation of the AWPR concept on the CRCT concept development platform. Figure 1 shows a CRCT Traffic Display of the Chicago (ZAU), Indianapolis (ZID) and Kansas City (ZKC) ARTCCs with depictions of both Next Generation Radar (NEXRAD) data and NCWF polygons. The polygons represent detections and predictions of severe convective weather extending out at 30-minute intervals. The NCWF includes only those forecasted areas meeting certain requirements for size and intensity. For example, an individual cell covering ten square miles or an area of moderate rain would not be included in a forecast intended for TFM decision support. The former having no strategic importance and the latter having no impact on traffic flow. The FAA requirements for storm minimum intensity and area of storm coverage are just two of the weather forecast questions that AWPR research will need to answer.

Once input by AWPR, NCWF polygons automatically become FCAs. However, if desired, manual FCA entry is still available for identification of weather or other flow-constrained areas. Also, we are exploring AWPR's use of other convective weather forecast products (e.g., CCFP and CIWS). As AWPR weather rerouting capability matures, it also may utilize other types of weather forecasts (e.g., icing, turbulence). Figure 2 shows the traffic that AWPR predicts will penetrate convective weather FCAs. A list of these flights is also available via the Flight Selector window (Figure 3).

Figure 4 depicts the Weather Rerouting window. A traffic flow specialist, in collaboration with other users, inputs reroute corridors by using a combination of mouse clicks on the Traffic Display (Figure 5a) and parameter selections (e.g., minutes until start of plan, time duration of plan) on the Weather Rerouting window (Figure 4). Figure 5a depicts reroute corridors to the north and south of an area impacted by weather FCAs. Additionally, there are reroute corridors located in a gap between the two principal portions of the storm. In creating such a plan, users can more effectively disperse controller workload across multiple sectors. For example, a reroute corridor may stretch across several sectors, so that workload associated with merging and diverging traffic entering or departing the corridor can be more evenly distributed. Although sectors near the storm could expect a high-level of traffic, associated controller workload might be more manageable, because the additional traffic would be more structured. Also, additional reroute corridors can be defined farther north or south to further disperse controller workload and/or increase traffic throughput. AWPR can also maintain controller workload at or below safe levels by linking reroute corridor flow rates to NAS Monitor traffic thresholds (Figure 6a and 6b). In this way, AWPR can fully utilize sector capacity without exceeding pre-determined limits.

The NAS Monitor displays in Figures 6a and 6b depict the maximum number of flights predicted to be in a given sector during a one- minute period. The example presented here uses the Indianapolis ARTCC. The vertical axis on the NAS Monitor display is divided into 24, 15-minute intervals. The horizontal axis identifies both individual sectors within the ARTCC (upper number) and the maximum number of aircraft allowed to be in each sector during a one-minute period (lower number) (i.e., sector loading limit).

Once TFM specialists define reroute corridors; AWPR allocates those flights that will penetrate the weather FCAs to the reroute corridors. The Flight Selector window (Figure 3) is used to identify flights that will penetrate FCAs and allows these flights to be examined using a sortable list. Users can also employ the Flight Selector window to add or remove flights to/from this list. The automation allows easy flight list modification. For example, arrivals and departures from airports near the storm or flights involving frequently used city pairs can be added to the list by simply filling in the origin/destination fields at the top of the Flight Selector window.

Next, AWPR automatically evaluates the weather reroute plan. The results of this evaluation, which takes less than a minute to perform, provide both visual and quantitative assessment criteria. An evaluation is essential to reassure NAS users that the plan will sustain high aircraft throughput around weather, reduce aircraft delays and cancellations, maintain safe levels of controller workload and ensure equity among carriers. The Traffic Display (Figure 5b) provides a visual representation of traffic predictions resulting from the plan. Additionally, Figures 6a and 6b depict the predicted change to sector loading. In Figure 6a (before the plan), sectors 30, 87-89 and 98 were predicted to exceed their sector loading thresholds during several 15-minute periods between 1330 and 1445. However, an examination of Figure 6b shows that no new NAS Monitor alerts resulted because of the plan (i.e., yellow or red boxes), demonstrating the effectiveness of linking the reroute corridor flow rate with NAS

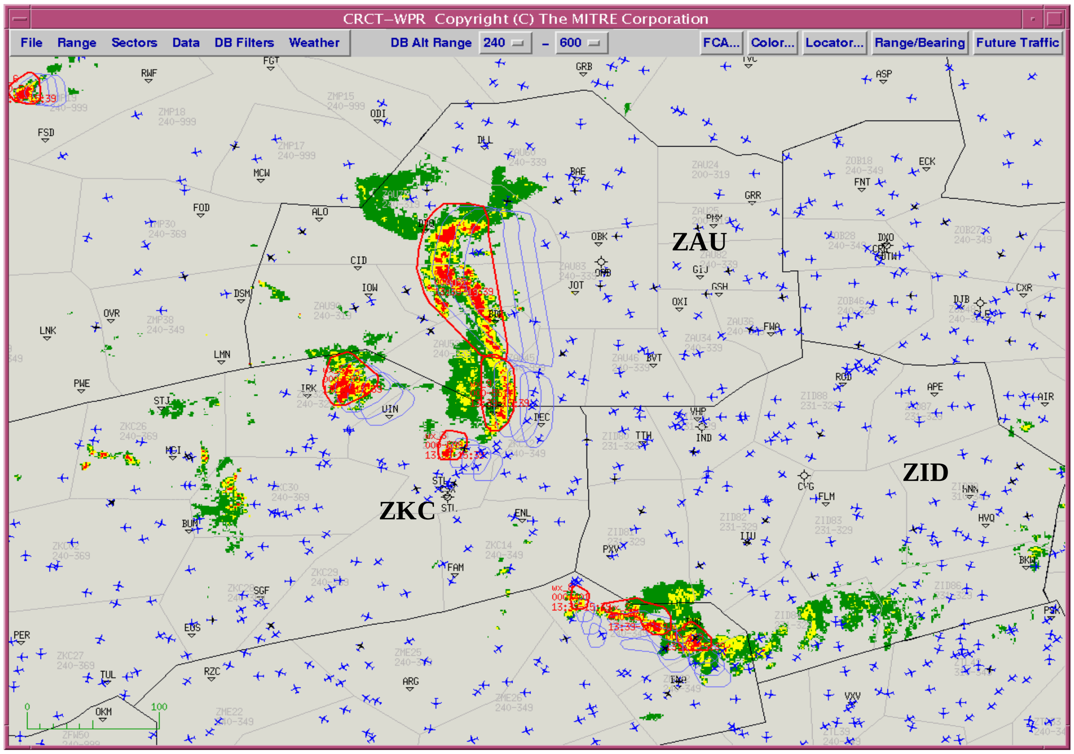

Figure 1. Traffic Display with Automated Weather FCAs

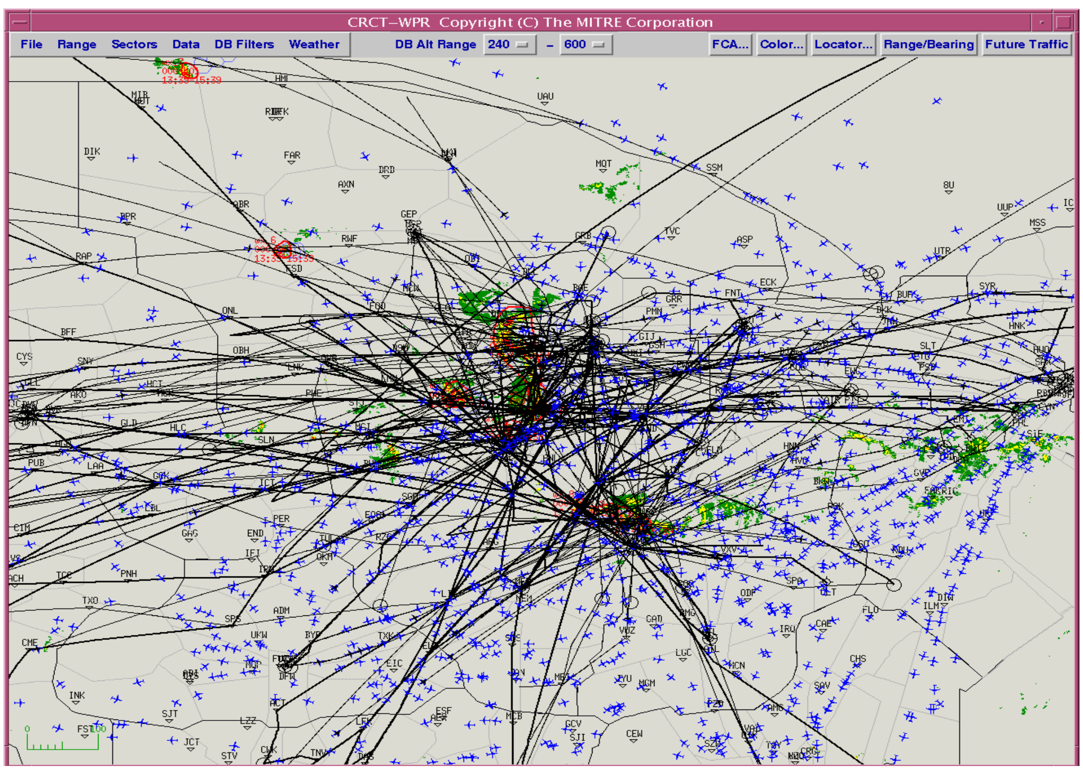

Figure 2. Flights with Trajectories Predicted to Intersect Weather FCAs (black lines)

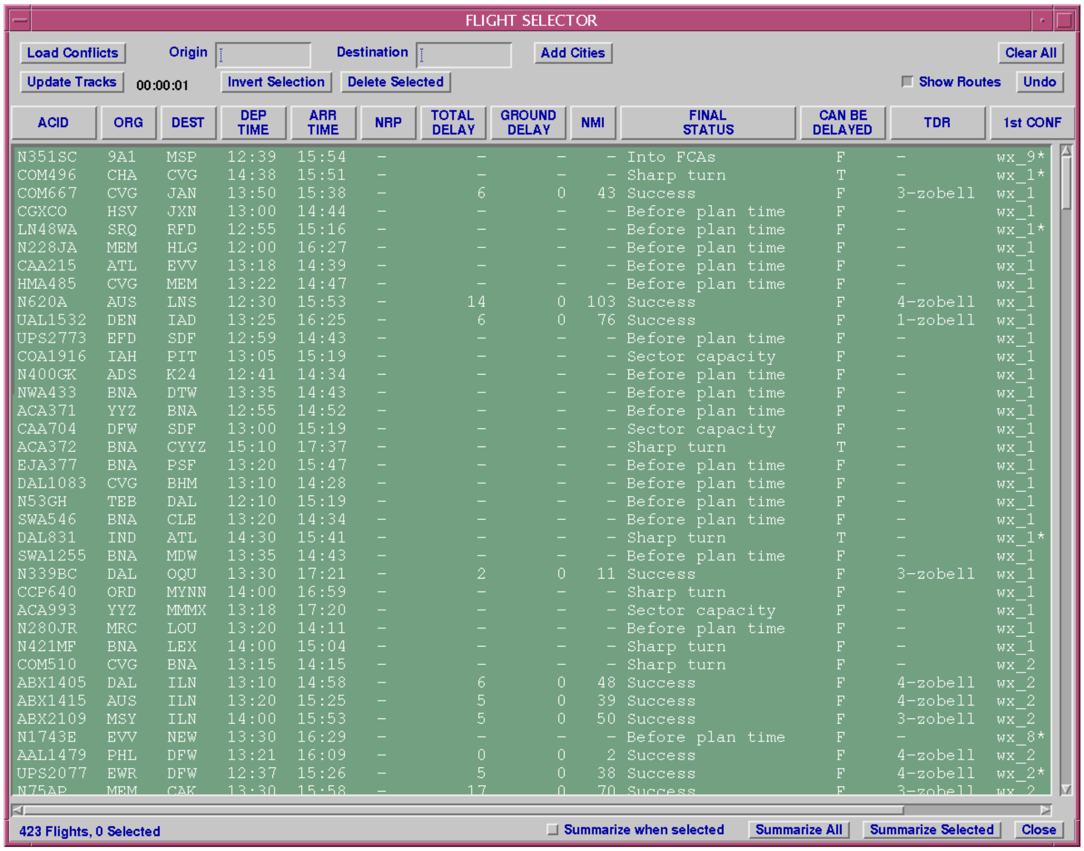

Figure 3. Flight Selector Window (Sortable Flight List)

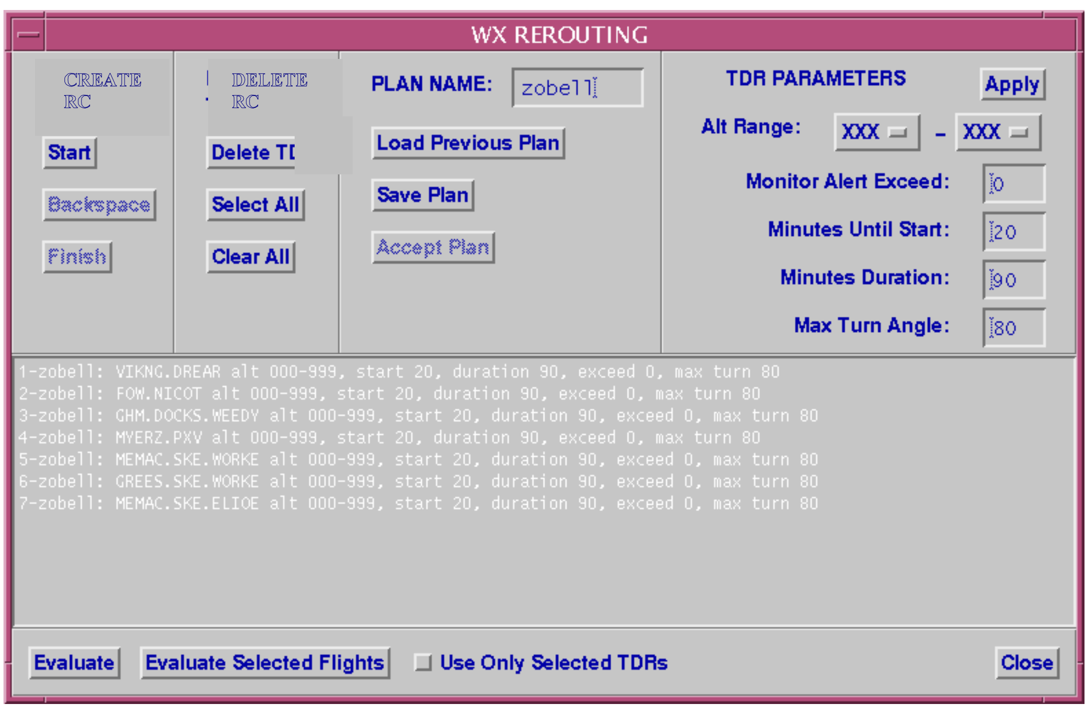

Figure 4. Weather Rerouting Window

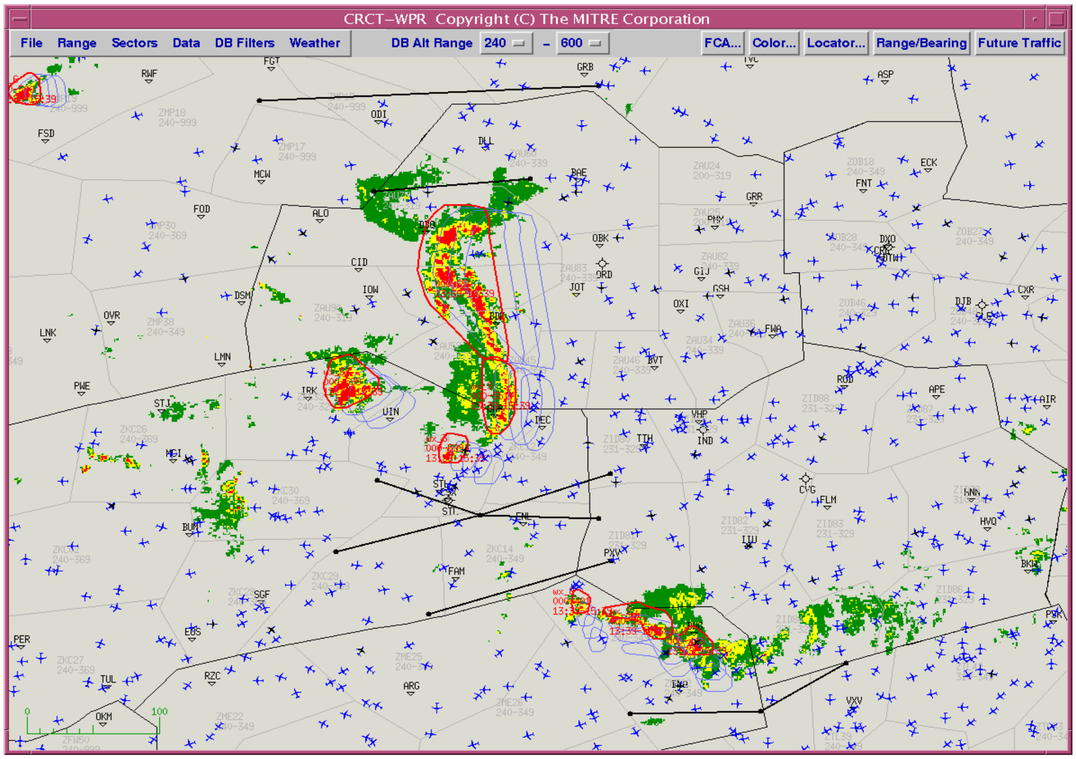

Figure 5a. Traffic Display with Weather FCAs and Reroute Corridors

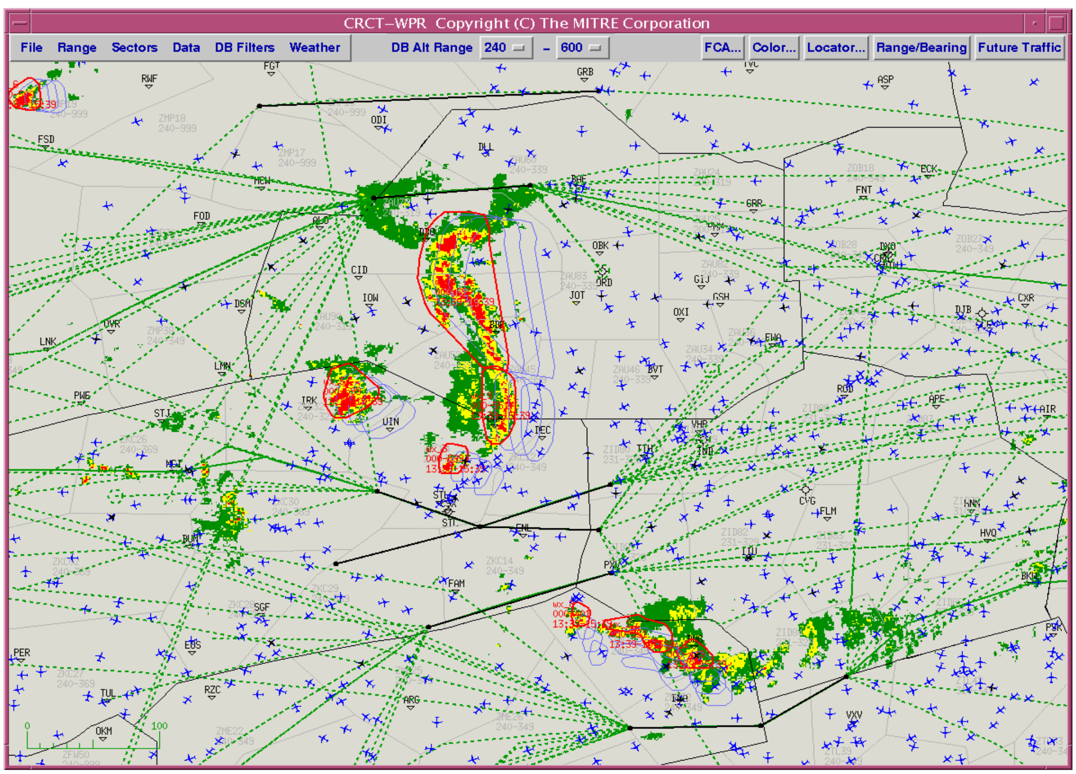

Figure 5b. Finished Plan With Reroutes Displayed (dashed green lines)

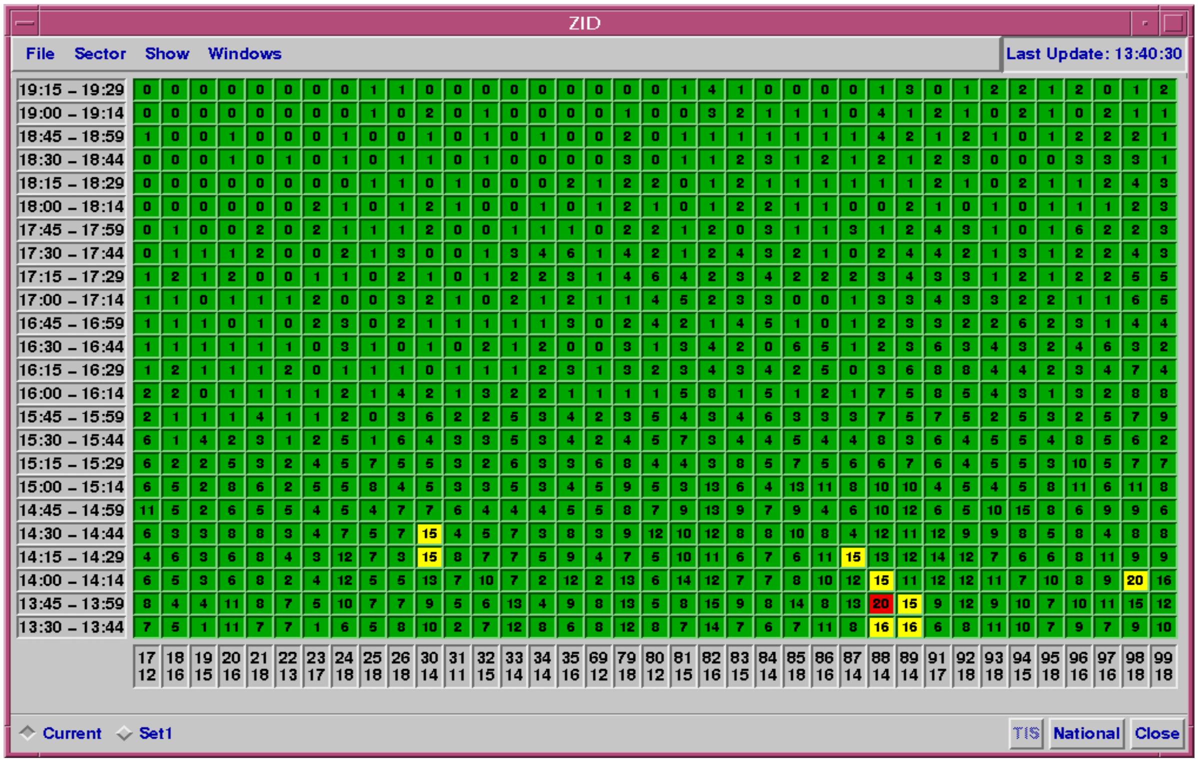

Figure 6a. Sector Count Predictions – NAS Monitor Before Plan

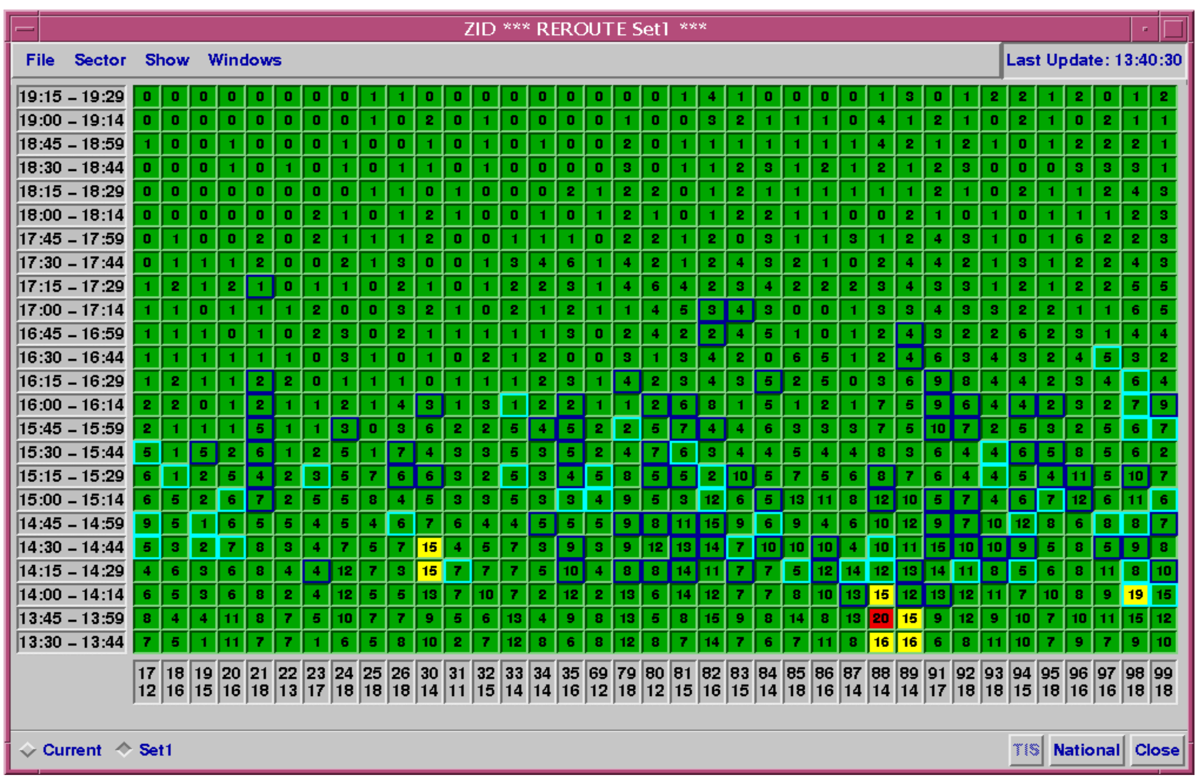

Figure 6b. Sector Count Predictions – NAS Monitor after Plan

Monitor sector threshold limits. The blue shading in Figure 6b represents increased (dark blue) and decreased (light blue) sector loading. Figure 7 depicts a graphical analysis of the plan. This quantitative assessment of predicted plan performance includes arrival delays, extra miles flown, ground delays, the percent of aircraft that the plan can successfully reroute, and the percent of aircraft that cannot be included in the plan (along with the related rationale for their exclusion). By knowing how many flights cannot be included in the plan and why, a modified plan can be proposed to improve on the overall plan performance.

6. EVALUATION RESULTS

In 2000, MITRE/CAASD assessed the accuracy of the NCWF, which AWPR utilizes. This assessment resulted in a recognition that convective weather forecasts need to develop algorithms to account for storm initiation, growth and decay. Promising research is being conducted in these areas by NCAR (Mueller, 2000) and MIT/LL (Wolfson, 1999). Also, convective weather forecasts need to extend out at least 2 hours and provide a vertical profile of storm tops in order to be more useful for weather reroute planning.

Also in 2000, MITTRE/CAASD conducted an initial assessment of AWPR. The MITRE/CAASD test subjects (i.e., former air traffic controllers and airline dispatchers) focused on:

- Applicability of the automation-assisted weather problem resolution concept to typical multi-center weather situations;
- Ability to provide acceptable situational awareness, rerouting options, and assessment metrics;
- Procedural adequacy for evaluating and resolving weather problems (i.e., analyzing traffic flow across weather polygons, constructing reroutes around weather and analyzing the effects of proposed reroutes); and
- Usability of the human-computer interface.

The 2000 laboratory assessment showed that the capabilities implemented in AWPR could be effective in dealing with large convective weather systems. Subjects indicated that AWPR provided:

- Increased situational awareness;
- Better understanding of the weather generated problem; and
- Improved ability for TFM and users to agree on rerouting plans.

Subjects suggested improvements to the human computer interface including:

- Better plan creation and editing capabilities;
- Integration with pre-stored reroute corridors (e.g., National Playbook routes);
- Better integration of plan and analysis, including integration of metrics into Traffic Display; and
- Incremental plan building.

Subjects believed that weather reroute plans should take into account:

- Improved sector complexity metrics; and
- Dynamic sector capacity limits.

Subjects also believed that weather reroute plans are more likely to be successful if there is data sharing between FAA and AOCs; and ATCSCC, ARTCCs and AOCs Collaboration. Also, performance results suggest that users should address weather problems early and incrementally as the weather develops, since rerouting options diminish as users begin to react tactically.

Field evaluations planned for the summer of 2001 did not take place due to the unavailability of operational personnel to participate in the evaluations. The large number of new TFM concepts and capabilities being evaluated is making assessment scheduling increasingly more difficult. However, the fact that the FAA and Industry are assessing so many promising capabilities is a very positive sign for the continued improvement of operational capabilities.

7. NEXT STEPS

Plans are underway to explore the integration of mature AWPR capabilities into the TFM tool set for the near-term by incorporating them with CRCT baseline functionalities. The remainder of AWPR capabilities will follow in the midterm as they mature. Field evaluations will be conducted in 2002 and beyond, to obtain operational feedback. These evaluations will include both FAA and industry personnel. During the evaluation process, we will identify weather data requirements with the help of the FAA/Industry user community. Weather research and development organizations will use these requirements to create future weather forecast products that will help increase aviation efficiency and safety, and provide the flying public with an improved level of service.

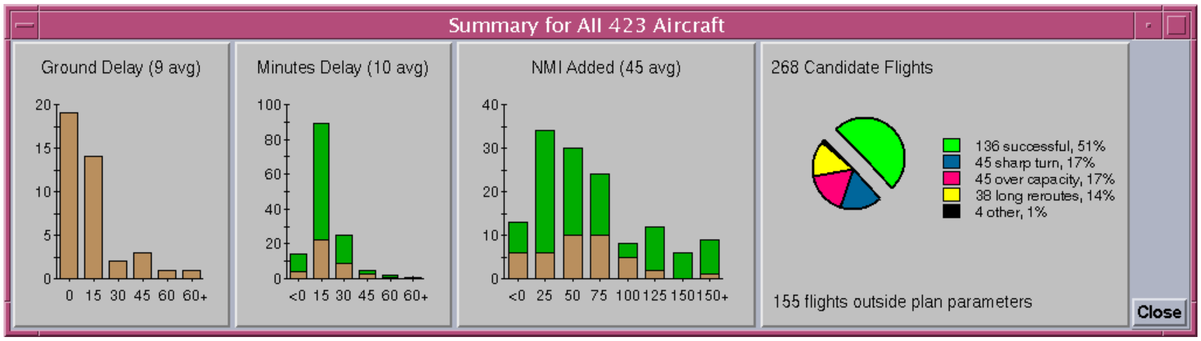

Figure 7. Plan Impact Assessment – Delays, Extra Miles Flown, and Success Summary

Future AWPR research will include:

- Applying automated aircraft decision logic and equitable allocation schemes to pre-stored reroute corridors and National Playbook routes;
- Utilizing the CCFP's more extended forecast to develop concepts for demand reduction in the 2-6 hour time frame, thereby reducing the magnitude of the weather rerouting problem in the 0-2 hour time frame;
- Continuing the research into equitable allocation and exploring additional rationing schemes;
- Continuing to integrate weather rerouting with other TFM capabilities such as altitude restrictions and MIT;
- Addressing the case of multiple, widely separated storms that may impact transcontinental flights;
- Enhancing plan evolution and updates over the life of a storm;
- Developing and evaluating operational concepts for collaborative decision making;
- Evaluating emerging and evolving convective weather forecast products; and
- Expanding the AWPR concept to assist with the restriction of capacity in severe weather areas.

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